SAFETY EVALUATION REPORT

RMI Forged Billets and Hanford RMI Billets in the Rev. 0 SARP of the Steel Banded Wooden Shipping Containers (SBWSC)

Docket No. 00-21-5467

Background

The criticality confirmatory evaluation in this Safety Evacuation Report (SER) addresses four types of the RMI Forged Billets (Mark I Inner, Mark I Outer, Mark IV Inner, and Mark IV Outer), and the Hanford RMI Billets (Mark I Outer) as described in the Rev. 0 SARP for the Steel Banded Wooden Shipping Containers (SBWSC). The RMI Forged Billets and the Hanford RMI Billets are unirradiated, low enrichment (0.956 and 1.256 wt.% U-235 max.) annular cylindrical ingots. The RMI Forged Billets have lengths (L) varying from 16 to 21 inches. The Hanford RMI Billets have the same outer and inner diameters as one of the RMI Forged Billets (Mark I Outer); their lengths (L) vary from 18 to 19 inches. The SARP proposes to ship the RMI Forged Billets and the Hanford RMI Billets in the SBWSC Model G-4255 in an exclusive use shipment.

The staff reviewed the criticality analyses presented in the SARP and performed independent confirmatory evaluation of criticality safety for the RMI Forged Billets and the Hanford RMI Billets. The staff confirmed that the Transport Index (TI), and the number of packages proposed in the Rev. 0 SARP for each of the payloads in an exclusive use shipment, meet the criticality safety requirements of 10 CFR 71 under normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

Other safety aspects (i.e., general information, structural, thermal, shielding, containment, operating procedures, acceptance tests and maintenance, and quality assurance) of the SBWSC have been reviewed for similar types of payloads in the Rev. G through Rev. L of the SARP and documented in the SER for the Rev. 11 through Rev. 19 of the Certificate of Compliance (CoC). The conclusions obtained in the earlier evaluation and SERs for the other safety aspects of the SBWSC remain valid and applicable to the payloads evaluated in this SER and will not be repeated.

Criticality Safety Evaluation

No special feature is incorporated in the design of the SBWSC for criticality control. According to 10 CFR 71, criticality safety must be demonstrated for a fissile material package under NCT and HAC. The hypothetical accidents consist of a sequence of events (e.g., vertical drops, fire, and immersion in water) that would damage the package and thus often represent a more limiting condition for criticality safety analysis; i.e., 2xN damaged array analysis where N is the number of packages in the array according to 10 CFR 71.59. In the criticality analysis for the SBWSC, the applicant conservatively assumed that all SBWSC in a shipment are burned during the 30-minute hypothetical accident fire (even though the wooden boxes are most likely only charred), and that the billets are "scattered and arranged" in the most reactive configuration with optimal interspersed hydrogenous moderation and total water (30 cm) reflection, as required by 10 CFR 71.55 and 10 CFR 71.59. The staff confirmed that the applicant has used the minimum length of the billets to establish the "maximum subcritical mass" for each of the RMI Billet types. The staff also confirmed that the applicant has indeed established the most reactive configuration for the number of billets (and packages) allowed in a shipment that would remain subcritical with an adequate safety margin.

Determination of Optimal Lattice Parameters and the Most Reactive Configuration

Determination of the maximum allowable number of RMI billets under the most reactive configuration begins with a search for the optimal lattice parameters, i.e., pitch, axial gap, and moderator density, that would maximize the neutron multiplication factor (k_∞) for an infinite array of billets in a close-packed, hexagonal lattice. The staff found that for a given uranium ingot composition and geometry, the k_∞ is mainly influenced by the amount of water in the unit cell for the hexagonal lattice configuration. Consequently, a loosely packed array with a relatively large pitch and axial gap and low moderator density can have a mass ratio of fissile to moderator material similar to that of a tightly packed array with a smaller pitch and axial gap, but higher moderator density. Infinite arrays of ingots having these two types of lattice parameters will have comparable k_∞ values, and thus can be regarded as equally reactive configurations. Determination of the most reactive configuration, therefore, must consider the effect of neutron leakage, which exists only for a finite array of ingots.

Since neutron leakage from a system reduces reactivity, the most reactive configuration for a finite array of ingots must be one with a minimum surface-to-volume ratio that gives the smallest total surface area for neutron leakage. A tightly packed array within a spherical enclosure and with total water reflection, therefore, should minimize neutron leakage. The staff has developed the necessary framework for determining the radius of the spherical enclosure for the finite array using iterative MCNP calculations (See "Criticality Control in Shipments of Fissile Material," J. R. Liaw and Y. Y. Liu, Proc. ANS Topical Meeting on Spent Fuel and Fissile Material Management, San Diego, CA., June 5-8, 2000, pp. 347-352).

The most reactive configuration of the finite array (and the maximum number of ingots allowed in a shipment) is determined when the adjusted effective neutron multiplication factor (k_{adj}) for the 2xN damaged array satisfies the following criterion,

$$k_{adj} = k_{eff} + 0.00258 + 2 \times (0.006^2 + s^2)^{0.5} < 0.95,$$

where k_{eff} and σ are the effective neutron multiplication factor and uncertainty, respectively, obtained in the MCNP calculations. The other constants in the equation are the code bias (0.00258) and uncertainty (0.006) obtained from benchmark calculations against the critical experiments. This is the same formula used by the applicant in the SARP, and the formula is consistent with that recommended in NUREG/CR-5661, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," April 1997.

Determination of Transport Index and Maximum Number of Packages per Shipment

The applicant followed the above procedure and determined the radius of spherical enclosure for the 2xN damaged arrays of each type of the RMI billets of 16-inch in length The amount of fissile material within the spherical enclosure is the "maximum subcritical mass" listed in the SARP (10,984 kg, 2,933 kg, 10,984 kg, 10,984 kg, and 2,933 kg) that corresponds, respectively, to the four types (Mark I Inner, Mark I Outer, Mark IV Inner, and Mark IV Outer) of RMI Forged Billets and the Hanford RMI Billets (Mark I Outer). The mass for each 21-inch-long RMI Forged Billet is 138.6 kg, 209.5 kg, 144.6 kg, and 217.4 kg, respectively. The mass for the 19-inch-long Hanford RMI billet is 189.5 kg. The applicant determined the allowable number of packages per shipment (2xN) by dividing the "maximum subcritical mass" by the amount per package (number of billets per package x the mass of the longest billet) for each of the selected payload types. By definition, the TI for criticality control is TI = 50/N, and the sum of TI of all packages should be less than 100 in an exclusive use shipment.

The maximum subcritical mass based on the 16-inch-long RMI Forged Billets can be used to establish the minimum Transport Index for billets of the same inner and outer diameters but longer lengths. The rule is conservative because fissile material of the same composition and total mass is generally more reactive in smaller physical dimensions. For example, the subcriticality mass limit for the 16-inch-long Mark I Outer RMI Forged Billets is 2,933 kg, which has been shown to meet the subcriticality requirement in the Rev. 0 SARP and confirmed by the staff confirmatory evaluation (see Table 1).

Table 1. Transport Index (TI) for Criticality Control for the Four RMI Forged Billets and the
Hanford RMI Billets in the SBWSC (Rev.0 SARP)

Payload ID/OD x L (in.)	SBWSC Model	Billets/ Package	Packages/ Shipment	Min. TI	k_{adj}	
					SARP	SER
RMI Forged Billets						
Mark I Inner 1.34/5.37 x 16-21	G-4255	4	19	5.1	0.9418	0.94448
Mark I Outer 2.80/6.98 x 16-21	G-4255	2	6	14.3	0.9438	0.94256
Mark IV Inner 1.26/5.46 x 16-21	G-4255	4	18	5.3	0.9361	0.94182
Mark IV Outer 2.51/6.98 x 16-21	G-4255	2	25	4.0	0.9339	0.93838
Hanford RMI Billets[*]						
Mark I Outer 2.80/6.98 x 18-19	G-4255	3	5	19.4	0.9438	0.94256
		2	7	13.0		
		1	15	6.5		

[*]There are three payload configurations for the Hanford RMI Billets and all are based on the same
maximum subcritical mass of 2,933 kg.

For the longer RMI Forged Billets that have the same outer and inner diameters as the 16-inch-long RMI Forged Billets, the applicant determined the allowable number of longer Billets in the 2xN damaged packages by dividing the maximum mass (2,933 kg) for the 16-inch-long Mark I Outer RMI Forged Billets by the mass (209.5 kg) of the 21-inch-long Mark I Outer RMI Forged Billets, i.e.,
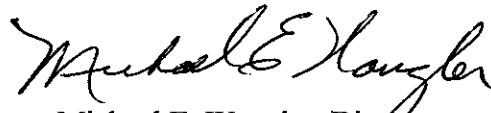
Number of 21-inch RMI Forged Billets in the 2xN damaged packages = 2,933/209.5 = 13.97.

Since there are two Mark I Outer Billets per package as indicated in Table 1.2.3-2 of the Rev. 0 SARP, the total number of 2xN damaged packages is 2xN = 13.97/2 = 6.98 and hence N = 3.49. The corresponding TI for criticality control can be calculated from TI = 50/N = 50/3.49 = 14.3. The staff has also confirmed the TI values for the other three types of RMI Forged Billets and the Hanford RMI Billets as listed in the Rev. 0 SARP and shown in Table 1. These TI values are acceptable for shipping the RMI Forged Billets of lengths between 16 and 21 inches and the Hanford RMI Mark I Outer Billets of lengths between 18 and 19 inches.

Table 1 gives the minimum TI values and other pertinent information for the four types of RMI Forged Billets and the Hanford RMI Billets in the designated SBWSC model. The last two columns in Table 1 give the k_{adj} values from the SARP and the staff's independent confirmatory analysis (labeled as SER) for the specified payload types. Based on the results in Table 1, the staff has thus independently confirmed that the k_{adj} values for shipping each of the four types of the RMI Forged Billets and the Hanford RMI Billets in the designated SBWSC Model meet the subcriticality criterion of 0.95 with adequate safety margin.

Summary

The staff has evaluated the criticality safety analyses presented in the Rev. 0 SARP for the RMI Forged Billets and the Hanford RMI Billets. The staff has performed independent calculations and confirmed that the minimum TI values (and the corresponding maximum number of packages) for the four payload types of the RMI Forged Billets and for the three payload configurations of the Hanford RMI Billets listed in Table 1.2.3-2 of the Rev. 0 SARP are conservative and meet the 10 CFR 71 requirements under NCT and HAC.

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